Maternal Linguistic Input and Executive Functioning in Prelingually Deafened Cochlear Implant Users

Honors Undergraduate Research Thesis

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Abstract

A cochlear implant (CI) is a biomedical device that provides the sensation of hearing to many individuals with profound-to-severe hearing loss. Prelingually deafened CI users are at an increased risk for delays and disturbances in neurocognitive skills including delays in executive function (EF): the self-regulation of cognitive and emotional processes during goal acquisition (Castellanos et al., 2015). In children who use CIs, as well as their normal hearing (NH) peers, the development of EF and language skills are closely tied (Hunter, Kronenberger, Castellanos, & Pisoni, 2017). Strong evidence shows that pediatric language skills are fostered by the language that mothers provide to their children, termed Maternal Linguistic Input (MLI; DesJardin & Eisenberg, 2007). However, research has not yet examined the role, if any, that MLI may play in the development of CI users' executive functioning skills. In this study, we sought to examine the relationship between MLI and children's attentional skills. Twelve mother-child dyads participated in a 5-minute free-play session and MLI was transcribed and categorized. Six CI users and six NH children completed language assessments through the Clinical Evaluation of Language Fundamentals for Preschoolers (CELF-P) and a digital assessment known as the Flanker task that measures inhibitory control and selective attention (Weintraub, Bauer, Zelazo, Wallner-Allen, Dikmen, Heaton, … & Gershon, 2013). Results suggested no significant differences between executive functioning skills between CI users and NH peers. However, CI users received significantly more maternal directives than their NH peers and, collapsed across hearing status, attentional directives were negatively associated with Flanker scores, suggesting associations between MLI and executive functioning skills. Further research is needed to understand the association between MLI and executive functioning skills that may promote the establishment of effective intervention strategies to support healthy neurocognitive development in pediatric CI users.

Chapter 1

Introduction and Literature Review

Individuals with severe-to-profound hearing loss may obtain the sensation of hearing through biomedical devices called cochlear implants (CI). The cochlear implant is a breakthrough surgical intervention established in the 1980s that provides auditory stimulation to children and adults with sensorineural hearing loss (Cruz, Quittner, Marker, & DesJardin, 2012). While many CI users experience success post-implantation in speech recognition and oral language acquisition, a portion of CI users still experience variable speech recognition and oral language outcomes even after long-term use (Castellanos, Pisoni, Yu, Chen, & Houston, 2018). Once implanted, the device produces a spectrally-degraded signal and thus the quality of auditory stimulation fundamentally differs between CI users and normal hearing (NH) individuals (Castellanos et al., 2018). Ninety percent of children born with sensorineural hearing loss are born to hearing parents, resulting in an immediate contrast in hearing status between mothers and children that may impact children's communication and language development (Cruz, Quittner, Marker, & DesJardin, 2012). Pediatric CI research has historically focused on speech and language outcomes following cochlear implantation yet pediatric CI users' limited access to sound can affect their entire neurocognitive development (Castellanos, Pisoni, Kronenberger, & Beer, 2016). Despite its critical clinical significance, neurocognitive deviations following cochlear implantation in pediatric CI users has been minimally researched.

Maternal Contributions to Children's Language Development

Parental factors are identified as highly influential in the development of language skills in children with and without hearing loss. For young children, parents serve as their primary source of language and the home environments that parents establish provide a foundation for children's language acquisition and development (Hoff, 2003). Demographic characteristics including socioeconomic status have also been associated with language skills for both normal hearing (NH) children and CI users (Hoff, 2003; Geers, Moog, Biedenstein, Brenner, & Hayes, 2009). A study by Hoff (2003) investigated families from high and middle socioeconomic status to observe the effects of different language-learning experiences on children's productive vocabulary development. Sixty-three families participated in this study with 2-year-old, NH children and dialogue between mothers and children in their home environment was transcribed while mothers completed three tasks: dressing their children, feeding them breakfast, and playing with toys provided by the experimenter (Hoff, 2003). Dialogue from these interactions was examined longitudinally and two 45-minute sessions were recorded over ten weeks (Hoff, 2003). Children from higher socioeconomic backgrounds exhibited faster expressive vocabulary growth than children from middle socioeconomic backgrounds (Hoff, 2003). Here, research suggests that differences in socioeconomic status impact children's language development by specifically influencing home environment and maternal speech.

The literature indicates mothers' education level also influences the language that mothers provide to their children and is a contributing factor for children's language development (Boons, De Raeve, Langereis, Peeraer, Wouters, van Wieringen, 2013; Conant, Liebenthal, Desai, & Binder, 2017; Magnuson, Sexton, Davis-Kean, & Huston, 2009). A study by Conant, Liebenthal, Desai, and Binder (2017) investigated children's perceptive language skills through their perception of phonemes, the basic units of sound that comprise words, and their association to maternal educational level. In this study, the brain activity of 32 NH children aged 7-12 years was analyzed via fMRI scans while they completed tasks measuring categorical proficiency, or the ability to discriminate phonemes from acoustic stimuli (Conant et al., 2017). Categorical proficiency is a significant component of language development because phonemes vary acoustically within an individual's speech as well as between speakers and the ability to recognize this variation allows individuals to comprehend spoken language across broad contexts (Conant et al., 2017). Participants completed a 2-alternative discrimination task in which they received pairs of acoustic stimuli and were required to determine if the second sound in the pair was identical to the first (Conant et al., 2017). In participants with lower categorical proficiency, researchers observed a positive association between maternal educational level and children's prefrontal cortex activity for participants with lower categorical proficiency. In other words, phonological awareness was modulated by maternal education for participants with lower categorical proficiency performance (Conant et al., 2017). This study found that maternal education may activate phoneme perception for elementary- and middle-school-aged children with lesser developed language skills. Overall, Conant and colleagues (2017) demonstrated an association between maternal education and children's language skills with both assessment-based and neurological data.

The association between maternal educational level and children's language skills has been researched in younger children as an opportunity to improve children's language skills and preschool preparedness. Magnuson, Sexton, Davis-Kean, and Huston (2009) studied these outcomes longitudinally for families in which mothers participated in continued education. Data on maternal education attained by 1,062 mothers with NH children was collected when children were born, 24 months of age, and 36 months of age (Magnuson et al., 2009). Children at 36 months of age were evaluated for school readiness by using an in-home assessment known as the Bracken Basic Concept Scale, which measures participants' knowledge of colors, shapes, letters, numbers, and comparisons (Magnuson et al., 2009). Global oral language skills were also evaluated at 36 months using the Reynell Developmental Language Scale (Reynell, 1990), an assessment administered during a laboratory session that required children to name objects and pictures (Magnuson et al., 2009). Researchers observed an association between maternal educational level and children's expressive and receptive language skills for mothers who had completed no more than a high school education at the time of their child's birth, indicating mothers with initially lower levels of education had the greatest opportunity to expand their child's language growth through their own educational advancement (Magnuson et al., 2009). These findings suggest an association between maternal educational level and language skill development in young children as well as an opportunity to bolster growth of children's language skills by promoting maternal education.

The association between maternal educational level and children's language development is not exclusive to NH populations. Boons and colleagues (2013) observed the significance of this association on spoken language skills in CI users aged 5-13 years and their NH peers. In this study, 66 CI users and their matched NH peers completed the *Bus Story* subtest of the Renfrew Language Scales (Renfrew, 1998) to measure their narrative language skills (Boons et al., 2013). Here, CI users were orally told a story about a bus and asked to retell the story using only spoken language. Upon analysis of demographic characteristics, researchers identified a "high potential" subgroup of bilateral CI users that received their first CI before 2 years of age and had no other developmental disabilities (Boons et al., 2013). Results indicated the "high potential" subgroup demonstrated better narrative language skills than other CI users and NH peers, and mothers of "high potential" CI users attained a significantly higher education level than mothers of other CI users and NH peers (Boons et al., 2013). Thus, this study found an association between maternal educational level and better narrative language skills within a subset of the pediatric CI population.

Similarly, Geers and colleagues (2009) investigated the language skills of CI users to observe the effects of auditory-oral intervention strategies with CI users and their NH parents. In this study, 153 CI users aged 5-7 years completed several assessments to assess their vocabulary skills after having used their CI devices for 1 year. Participants were administered the Expressive One-Word Picture Vocabulary Test (Gardner, 2000) and Expressive Vocabulary Test (Williams, 1997), both of which required participants to name a series of pictures to evaluate the quantity and quality of participants' vocabulary (Geers, Moog, Biedenstein, Brenner, & Hayes, 2009). To account for differences in oral language skills, participants were also administered nonverbal assessments including the Peabody Picture Vocabulary Test (Dunn & Dunn, 1997) and Receptive One-Word Picture Vocabulary Test (Brownell, 2000), both of which required participants to select one of four images that represented a word named by the experimenter (Geers et al., 2009). Finally, oral language skills were assessed using the Clinical Evaluation of Language Fundamentals (CELF; Wiig, Secord, & Semel, 1992). In the CELF, participants completed subtests of this evaluation to measure their receptive language skills and expressive language skills by pointing to images corresponding to oral commands provided by the experimenter, increasing in length and complexity throughout the evaluation (Geers et al., 2009). Results revealed significant variance in CI users' language outcomes associated with parental education level for global language skills (Geers et al., 2009). Thus, parental education frames the home environment which fosters children's ability to acquire and develop vocabulary skills. This research further strengthens the association between socioeconomic status and children's language development and provides an understanding of this relationship within pediatric CI populations. Maternal Linguistic Input (MLI) serves as a model for children's language development and thus demographic variables including maternal educational level and socioeconomic status that influence mothers' language skills influence language development for their children.

Beyond demographic factors, previous research has also identified maternal involvement and mothers' self-efficacy as critical variables for children's language development (Cruz, Quittner, Marker, & DesJardin, 2012; DesJardin & Eisenberg, 2007; Majorano & Lavelli, 2013). DesJardin and Eisenberg (2007) define self-efficacy as parents' belief in their ability to perform certain parental tasks based on both their knowledge of the task and confidence in their roles as parents (DesJardin & Eisenberg, 2007). Parental involvement and self-efficacy are instrumental in the development of language skills for children regardless of hearing status. For children with and without hearing loss, academic success has been positively associated with parental involvement (DesJardin & Eisenberg, 2007). Specific to children with hearing loss, parental involvement through activities such as joint storybook reading can assist with children's language growth (DesJardin, Ambrose, & Eisenberg, 2008). In addition, a study by Moeller (2000) explored the relationship between language outcomes in children who are deaf and hard-of-hearing and family involvement. In this study, 112 5-year-old children with hearing loss participating in a multidisciplinary, family-oriented intervention program (Moeller, 2000). To assess their vocabulary skills, participants were administered the Peabody Picture Vocabulary Test (Dunn & Dunn, 1981) in which children were required to point to a picture representing a spoken word provided by the trained experimenter (Moeller, 2000). Family involvement was characterized on a rating scale representing families' participation in components of the intervention program, including weekly home visits and a parental support group. Scores were provided on a scale from 1 (limited participation) to 5 (ideal participation) based on participation factors such as parents' attendance at program meetings, participation during each session, and effectiveness of communication with their child (Moeller, 2000). Results revealed a positive correlation between parental involvement and children's vocabulary scores, indicating parents with greater involvement communicated more effectively with their children and fostered more language skills (Moeller, 2000). This study demonstrated that active family involvement in intervention programs contributes to better language outcomes for children with mild to profound hearing loss.

Similarly, research studies have examined how family involvement influences language outcomes in CI users. In DesJardin and Eisenberg's study (2007), 32 CI users aged 2-7 years and their NH mothers participated in a free-play and storybook task, during which their dialogue was transcribed. In the free-play task, mothers were simply instructed to play with their children as they normally would at home with toys provided by the experimenters. In the storybook task, mothers were similarly provided with two age-appropriate storybooks and instructed to read with their child as they normally would at home, either narrating the book themselves or encouraging their children to narrate the story (DesJardin & Eisenberg, 2007). All MLI was transcribed, and maternal utterances were categorized by facilitative language techniques, or the communication strategy used to promote language with their child (DesJardin & Eisenberg, 2007). Maternal involvement was assessed through the scale of parental involvement and maternal self-efficacy, developed by the experimenters, in which mothers rated questions on a scale from 1 (not at all) to 7 (very much) regarding their perceived influence on their child's auditory development and involvement in their child's intervention or school program (DesJardin & Eisenberg, 2007). DesJardin and Eisenberg (2007) found that mothers' use of more complex facilitative language techniques promoted their child's language abilities and mothers with greater perceived involvement and self-efficacy utilized more complex language, suggesting an association between mothers' perceived abilities and the linguistic experiences they provide to their children (DesJardin & Eisenberg, 2007). These findings suggest that mothers' self-efficacy and involvement in intervention and educational programs influence the linguistic information they provide to their children and variable language outcomes experienced by CI users may be partially attributed to differences in maternal contributions.

While the reviewed literature suggests a significant association between maternal involvement and children's language outcomes for both CI users and NH peers, maternal involvement itself differs between hearing mothers of hearing children and hearing mothers of deaf children. Fagan, Bergeson, and Morris (2014) define these pairings as matched-hearing dyads and mixed-hearing dyads, respectively. Maternal contributions to these dyadic interactions are twofold and are influenced by both mothers' perceptions of children's abilities as well as children's demonstration of language skills (DesJardin & Eisenberg, 2007). Mothers and children influence the behavior of one another, yet the dynamic nature of this relationship makes it impossible to determine the directionality (DesJardin & Eisenberg, 2007). It is possible, in mixed-hearing dyads, that mothers' perceptions of their children's abilities may not be an accurate assessment of their language skills. A study by Bergeson, Miller, and McCune (2006) investigated this concept further by researching the influences of hearing status and age on maternal speech used with infants. In this study, 9 CI users aged 10-37 months were matched by chronological age and hearing age, or the duration of CI use, to NH controls (Bergeson, Miller, & McCune, 2006). Infants and their NH mothers participated in a free-play session with age-appropriate toys and all MLI was transcribed. The results indicated that all mothers used shorter utterances, utterances higher in pitch, and longer pauses between utterances, characteristics of infant-directed speech, when speaking to their infants compared to speaking with the adult experimenter (Bergeson, Miller, & McCune, 2006). Interestingly, mothers of CI users utilized infant-directed speech consistent with mothers of NH children when matched by hearing age rather than chronological age, indicating mothers' pitch was a function of their child's hearing experience (Bergeson, Miller, & McCune, 2006). Thus, hearing age may serve as a contributing factor of MLI and mothers' perception of their children's language abilities may be confounded by their child's hearing status.

The literature provides potential explanations for these differences observed between maternal speech and children's hearing status. While the factors contributing to this variability are debated, there are two hypotheses that seek to explain the differences in language provided to children with language impairments, including many children with hearing loss: (1) parents compensate for their child's limited language skills and (2) parents adjust the language they provide to meet their child's ability level (Majorano & Lavelli, 2013). Majorano and Lavelli (2013) tested these hypotheses by researching the ability of MLI to match children's language profiles. Fourteen children with Specific Language Impairment (SLI) and their chronological age-matched and language age-matched peers participated in a storybook task with their mothers (Majorano & Lavelli, 2013). Mothers were instructed to read a descriptive book with their child in their normal home environment and two sessions of this shared reading were recorded and transcribed. Upon phonological and lexical analysis, researchers found children with SLI and their mothers used adjectives and adverbs of lower phonological complexity with greater frequency than mother-child dyads matched on chronological age (Majorano & Lavelli, 2013). This suggest that mothers of children with SLI may adapt their language to produce words that are more accessible, fine-tuning their MLI to their child's linguistic limitations (Majorano & Lavelli, 2013). While this study investigated maternal language in children with language impairments in the absence of sensory-neural hearing loss, the findings provide an applicable understanding of support for mothers' ability to tune their language to their child's speech production.

MLI can be utilized to strategically foster language development in children through facilitative language techniques (FLTs, Cruz et al., 2012). FLTs are qualitative measures of MLI that researchers suggest may be used to cultivate language skills and this has significant implications for CI users (DesJardin & Eisenberg, 2007). DesJardin, Ambrose, and Eisenberg

(2008) have classified FLTs based on their ability to promote language. In their longitudinal study, 16 CI users aged 2-6 years and their NH mothers participated in two testing sessions, 3 years apart. During the first session, children were administered the Reynell Developmental Language Scales (Reynell, 1990) to assess their baseline expressive and receptive language skills (DesJardin, Ambrose, & Eisenberg, 2008). Mothers and children also completed a storybook task in which mothers were instructed to interact with their children as they normally would at home while reading two age-appropriate storybooks. MLI during this task was recorded and transcribed. At the second session, children were administered the Oral Written Language Scales (Carrow-Woolfolk, 1995) to assess their language comprehension through picture selection and sentence completion (DesJardin, Ambrose, & Eisenberg, 2008). Phonological awareness was also assessed at this time through the Phonological Awareness Test (Robertson & Sattler, 1997) that measured children's phonological skills including rhyme, segmentation, isolation, deletion, blending, and graphemes (DesJardin, Ambrose, & Eisenberg, 2008). Finally, the Woodcock-Johnson-III Diagnostic Reading Battery (Woodcock, Mather, & Schrank, 2004) was administered to assess children's skills in brief reading (DesJardin, Ambrose, & Eisenberg, 2008). Results indicated that mothers' use of higher-level FLTs, such as open-ended questions that allow children to answer with more than one word, during the first session were associated with increased literacy and vocabulary skills 3 years later (DesJardin, Ambrose, & Eisenberg, 2008). In contrast, mothers' use of lower-level FLTs, such as directives that command physical behavior without initiating dialogue, did not have an association with language skills (DesJardin, Ambrose, & Eisenberg, 2008). Similar to findings observed in DesJardin and Eisenberg's previous study (2007), FLTs of greater complexity were associated with children's language skills (DesJardin & Eisenberg, 2007). This research supports that among CI users, mothers' use of higher-level FLTs that encourage conversation and elicit more complex grammatical structures are associated with growth in CI users' language skills.

The quality of MLI has significant effects on language outcomes for both NH children and CI users, though the complexity of MLI may differ between these groups. A study by Fagan, Bergeson, and Morris (2014) examined complexity and directiveness of mothers' interactions with children before and after cochlear implantation. In their study, 9 matched-hearing and 9 mixed-hearing mother-infant dyads were observed at two time points, on average 9.7 months apart, before children reached 24 months of age (Fagan, Bergeson, & Morris, 2014). At both time points before and after implantation, dyads participated in a free-play task with toys provided by the experimenters and mothers were instructed to interact normally with their child. MLI was recorded and transcribed during both sessions for comparison (Fagan, Bergeson, & Morris, 2014). Analysis of the MLI revealed that before and after cochlear implantation, mothers of mixed-hearing dyads used more prohibitions and directives to control their child's behavior (Fagan, Bergeson, & Morris, 2014). Additionally, the mean length of maternal utterances, quantified by the average number of morphemes used per maternal utterance, was significantly less complex in mixed-hearing dyads at both time points (Fagan, Bergeson, & Morris, 2014). These findings indicate that mothers' use of less complex language for newly implanted CI users may be attributed to both an inability to either (1) fine-tune maternal language to children's language skills or (2) as a response to children's limited language acquisition before acclimation to their CI, as proposed by Majorano and Lavelli (2013). Mothers' use of utterances with greater grammatical and syntactical complexity, determined by the quantity of words and morphemes, promotes advanced language development in their children and indicates their perception of their child's abilities to comprehend and engage in dialogue with complex language.

An additional finding of the Fagan, Bergeson, and Morris study (2014) emphasizes another aspect of MLI that influences children's language development: conversational turns. Conversational turns, or turn-taking, refers to the back-and-forth interaction between mothers and children in dialogue that provides a measurement of the synchrony of their interaction (Romeo, Leonard, Robinson, West, Mackey, Rowe, & Gabrieli, 2018). In the Fagan, Bergeson, and Morris study (2014), mixed-hearing dyads before cochlear implantation exhibited more dyssynchronous interactions, meaning maternal utterances frequently overlapped children's utterances (Fagan, Bergeson, & Morris, 2014). This finding indicates an association between hearing loss and a lack of turn-taking skills that prevent dyads from predicting the timing and topic of each speaker's utterances.

Conversational turns were a key interest in a study by Romeo and colleagues (2018) investigating children's language exposure. In this study, parents of 36 children aged 4-6 years were provided with LENA digital language processing devices to record audio in their home environment over 2 consecutive days (Romeo et al., 2018). LENA speech-identification algorithms were then used to synthesize utterances between parents and children. Children additionally participated in a story-listening functional MRI task in which they listened to short, narrative stories and received visual and audio reminders to listen attentively while scans were taken of their brains to observe brain activation (Romeo et al., 2018). Analysis of fMRI scans revealed that children who participated in more conversational turns with their parents at home exhibited greater brain activation in their Broca's area, the region of the frontal lobe associated with language processing and speech production (Romeo et al., 2018). This finding indicates an association between children's linguistic environment and neural language processing and supports a positive relationship between conversational turns and increased language skills (Romeo et al., 2018). As previous research has indicated, the ability to engage in synchronous, topical conversation with parents is a critical tool for children's acquisition of language skills and conversational turns provide an objective measure of the fluidity in maternal-child dialogue that is facilitated by MLI.

The Development of Children's Cognitive Skills

CI users receive degraded bottom-up, or sensory, input compared to NH peers. This occurs through electrical stimulation of the auditory nerve. While spectrally degraded, the stimulation is used by the brain for speech recognition (Moberly, Houston, & Castellanos, 2016). However, top-down neurocognitive processes may also contribute to differences in CI users' language development. Executive function (EF) is an umbrella term for the top-down neurocognitive processes involved in self-regulation and goal-oriented action (Zelazo & Carson, 2016). Of the family of processes categorized under executive function, three are generally agreed to be core skills: (1) attentional shifting, the ability to change perspective, (2) working memory, the ability to store information in the mind to retrieve later, and (3) inhibition-concentration, the ability to selectively focus attention on certain stimuli and suppress other stimuli (Diamond, 2013).

Though these skills develop across the lifespan, the preschool period is critical for the rapid development of executive function due to the growth of neural networks in the prefrontal cortex, the region of the brain involved in complex behavior and decision-making (Zelazo & Carson, 2014). Specifically, the early development of inhibitory control allows individuals to control their attention, behavior, and emotions such that they may override internal impulses. While this is challenging for young children, inhibitory control is critical throughout development in order to exhibit appropriate social interactions, complete complex tasks, and attain goals (Diamond, 2013).

Current literature suggests NH children's executive functioning skills at the preschool age are a significant predictor of developmental outcomes into adulthood, including physical and psychosocial well-being (Bailey, 2007; Diamond, 2005; Moffitt, Arsenault, Belsky, Dickson, Hancox, Harrington… & Caspi, 2011; Taylor-Tavares et al., 2007). A longitudinal study by Moffitt and colleagues (2011) observed the development of executive functioning skills in a cohort of 1,000 participants across a broad socioeconomic spectrum to investigate community health, wealth, and crime rates. NH participants were followed from birth to 32 years of age and completed nine assessments of self-control assessed by parents, teachers, and a professional psychiatrist, including participant self-assessments at 5, 7, 9, and 11 years of age (Moffitt et al., 2011). At 32 years of age, participants completed clinical assessments to measure overall health and self-evaluations to collect lifestyle data on socioeconomic status, substance dependence, and criminal activity (Moffitt et al., 2011). Fascinatingly, children who exhibited greater inhibitory control skills at ages 3-11 years exhibited lower engagement in substance use as teenagers and were less likely to have alcohol or drug issues as adults. When compared to data collected at 32 years of age, these children were less likely to have experienced criminal activity or financial instability as adults and less likely to experience health concerns (Moffitt et al., 2011). These findings reveal strong associations between inhibitory control and physical, mental, and social health as well as the predictive value of children's inhibitory control skills on long-term societal outcomes.

While the ability to use executive functioning skills as a predictive measure for children indicates some long-term stability, executive function is comprised of a variety of distinct skills that impose independent effects on development. Thus, there is an opportunity for isolation and intervention of executive functioning skills along the developmental pathway (Figueras, Edwards, & Langdon, 2008). The plasticity of the human brain and susceptibility to environmental and contextual changes further suggest variations in executive function that can be harnessed for interventions to enhance executive functioning skills (Zelazo, 2012). Researchers and clinicians are increasingly turning to EF to predict developmental outcomes and enhance the skills necessary for physical, social, and psychological health across the lifespan.

For both pediatric CI users and their NH peers, the development of language skills is closely tied to the development of executive functioning skills (Hunter, Kronenberger, Castellanos, & Pisoni, 2017). Among preschool aged NH children, research has found higher executive functioning skills are associated with greater math and reading competency and serves as a stronger measure of school readiness than nonverbal intelligence (Blair & Razza, 2007). Similar findings have been observed in older children with varying degrees of hearing loss (deaf and hard of hearing, D/HoH). A study by Figueras, Edwards, and Langdon (2008) evaluated language and executive functioning skills among CI users, non-implanted deaf children, and NH children. In their study, 22 CI users, 25 non-implanted deaf children, and 22 hearing controls aged 8-12 years were assessed on their spoken language abilities (Figueras, Edwards, & Langdon, 2008). Participants were administered The British Picture Vocabulary Scale (Dunn, Dunn, Whetton, & Pintilie, 1982), in which participants were asked to repeat a spoken word before pointing to a picture representing the word, and the Test for Reception of Grammar (Bishop, 2003), in which participants selected one of four images that corresponded to a spoken sentence (Figueras, Edwards, & Langdon, 2008). To assess executive functioning skills, participants completed six tasks from the NEPSY neurocognitive battery (Korkman, Kirk, & Kemp, 2007): (1) Tower Task, measuring planning and problem solving, (2) Visual Attention, measuring selective attention (3) Design Fluency, measuring creativity, (4) Knock and Tap, measuring self-regulation, (5) Day-Night, measuring inhibition concentration skills, and (6) Card Sorting, measuring concept formation skills (Figueras, Edwards, & Langdon, 2008). Results indicated that CI users and non-implanted deaf children exhibited poorer oral language skills than NH peers. However, across the D/HoH sample, researchers observed significant associations between oral language skills and executive functioning skills including inhibition and working memory (Figueras, Edwards, & Langdon, 2008). As observed by these studies, language skills are associated with executive functioning skills for both CI users and their NH peers, and promotion of CI users' language skills may be achieved by increased executive functioning skills.

Previous research has further investigated the relationship between executive functioning and language skills in CI users. A recent study by Hunter, Kronenberger, Castellanos, and Pisoni (2017) examined speech-language skills in deaf children following the first two years after cochlear implantation and again after having used their CIs for seven years or more. Thirty-six. participants initially aged 2-6 years completed several assessments to measure speech-language skills (Hunter, Kronenberger, Castellanos, & Pisoni, 2017). The Reynell Developmental Language Scales (Reynell, 1990) were administered to evaluate participants' language development through the use of picture books and props. Speech perception was measured by the Pediatric Speech Intelligibility Test (Jerger & Jerger, 1984) in which participants pointed to pictures that represented spoken words and sentences. Lastly, participants completed the Mr. Potato Head task in which they were provided with spoken directions and demonstrated their understanding by producing the action with a Mr. Potato Head toy (Hunter et al., 2017). In the final testing session of this longitudinal study, long-term neurocognitive outcomes were measured through a battery of assessments that quantified language, verbal working memory, visual-spatial working memory, fluency-speed, and inhibition-concentration skills associated with executive functioning (Hunter et al., 2017). Data collected early after cochlear implantation indicated CI users' speech-language skills at 6 months after implantation predicted their long-term language and neurocognitive outcomes and this predictive ability was even greater for speech-language skills measured at 18 months after implantation (Hunter et al., 2017). Specifically, results revealed associations between early speech-language skills and long-term working memory (Hunter et al., 2017). In summary, research has demonstrated both short-term and long-term implications of early language skills and EF development in both NH children and CI users and significant variations in language development between these groups.

Current Study

Despite extensive research on the associations between cochlear implantation and language acquisition and the associations between children's language and executive functioning skills, research has yet to examine the association between MLI and children's executive functioning skills. The current study examined the associations between qualitative and quantitative aspects of MLI and children's inhibition-concentration skills in pediatric CI users and their NH peers. Specifically, there were 2 hypotheses: (1) the auditory deprivation experienced by CI users that commonly causes delays in language would negatively impact executive functioning skills as well and (2) a relationship would exist between MLI and children's executive functioning skills. This would be demonstrated by associations between increased MLI measures that promote language development and increased inhibition-concentration scores, regardless of hearing status. Specifically, we anticipated increased frequencies of open-ended questions and decreased frequencies of directives associated with greater inhibition-concentration scores. Additionally, we anticipated greater mean length of utterances (MLU) produced by mothers as well as increased frequencies of conversational turns associated with greater inhibition-concentration scores. Therefore, this research study examined the relationships between MLI and executive functioning skills in a clinical population of pediatric CI users and NH controls.

The literature reviewed provided an extensive model of maternal language categorization through facilitative language techniques (FLTs). However, several FLT categories were found to have insignificant effects on language and were used infrequently among the preschool age group (DesJardin et al., 2008; DesJardin & Eisenberg, 2007; Fagan et al., 2014). The categories of MLI in this study represent collapsed FLT categories appropriate for our participants. Additionally, several studies in the reviewed literature elicited MLI through structured tasks rather than free-play tasks. DesJardin and Eisenberg's study (2007), for example, generated MLI through joint storybook reading in which mothers were provided with age-appropriate picture books and instructed to interact with their children as they normally would at home (DesJardin et al., 2008; DesJardin & Eisenberg, 2007). While structured tasks have been shown to produce more communication between parents and children, we utilized the unstructured free-play task to simulate a more natural home environment within our testing center to model everyday language between mother-child dyads.

Chapter 2

Methods

Participants

Study participants were drawn from a sample of 12 mother-child dyads who volunteered to be contacted for research and who were evaluated as part of a larger, longitudinal study of psychosocial outcomes following pediatric cochlear implantation. This included 6 mixed-hearing dyads of early-implanted pediatric CI users with their NH mothers and 6 matched-hearing dyads of NH children with their NH mothers. All child participants were matched 1:1 by age (+/- 6 months) and nonverbal intelligence (+/-1 *SD*).

Pediatric participants were aged 3 to 6 years ($M = 4.61$, $SD = .92$) upon entering the study and did not have developmental, cognitive, or neurological diagnoses. All participants used spoken English as the primary language in their home environment and were enrolled in an educational setting outside of the home, such as preschool, at the time of study entry. Participants were evaluated by a trained experimenter using The Primary Test of Nonverbal Intelligence (PTONI, Ehrler & McGhee, 2008) to attain a nonverbal intelligence score and scores greater than or equal to 70 were necessary for inclusion. For inclusion in the study, NH children also tested within normal range of hearing as assessed by a hearing screening (20 dB HL at 500, 1000, 2000, and 4000 Hz) and exhibited typical language development as assessed by a parent-completed report.

For inclusion in the study, CI participants also presented with bilateral severe-to-profound hearing loss (>70 dB HL) prior to age 3 years, at least one multichannel CI activated by age 3 years, use of their CI for at least 1 year, and enrollment in an aural-oral educational/therapy program at the time of study entry. All testing for this experiment was conducted at Ohio State's Eye and Ear Institute in Columbus, Ohio. The Eye and Ear Institute provides a range of services for pediatric individuals with hearing loss in the Department of Otolaryngology – Head & Neck Surgery. All experimenters were trained and supervised by Dr. Castellanos. The present study was approved by The Ohio State University Institutional Review Board. Participants were consented on their participation in this study and received compensation for participation.

Measures

Performance-based assessments were utilized in this study. The Clinical Evaluation of Language Fundamentals for Preschool (CELF-P, Semel, Wiig, & Secord, 2004) was administered by a trained experimenter to assess oral language skills for children aged 3 to 6 years. Children were administered the *Sentence Structure*, *Word Structure*, and *Expressive Vocabulary* subtests of the CELF-P. These scores were summed and age-corrected to produce Standard scores.

Measures of MLI were collected during a mother-child play task. Mother-child dyads participated in a 5-minute free-play session with age-appropriate toys and their dialogue was transcribed. A shelf of more attractive toys was located within the testing room. Prior to the free-play session, mothers were provided with two instructions from the experimenter: (1) to play with their children as they naturally would at home with toys provided on the table located in the testing room (see Figure 1) and (2) to instruct their child not to play with the toys on the shelf. While the free-play task sought to assess MLI, this component required children to exhibit executive functioning skills by adhering to mothers' instructions and resisting their impulse to play with the more attractive, prohibited toys. Dialogue from each play session was transcribed by 3 independent transcribers and reached 100% reliability.

The Flanker Inhibitory Control and Attentional Test of the National Institute of Health (NIH) Toolbox was utilized to assess child participants' executive functioning skills. The NIH Toolbox is a comprehensive set of computerized assessments of cognition that children complete on an iPad device (Zelazo et al., 2013). Of these assessments, the Flanker Test is an objective measure of inhibition-concentration. The Flanker begins with practice trials in which participants are shown a row of fish icons and given visual cues and audio instructions to select the arrow that represents the direction the middle fish is facing, either the same direction (congruent condition) or the opposite direction (incongruent condition) as the other fish on the screen (see Figure 2). This requires participants to focus their attention on the central fish while inhibiting their attention to the other fish, thus demonstrating inhibition-concentration skills. Participants are presented with two buttons at the bottom of their iPad screen, a left arrow and a right arrow, and are asked to press the button that indicates which direction the middle fish is facing (see Figure 3). This repeats for a total of 5 practice trials with participants receiving visual and audio cues to redirect their attention toward the middle of the screen in between each trial.

After 5 practice trials, participants complete 20 scored trials with only audio cues to direct their attention toward the middle of the screen. Participants who complete 20 trials with 90% accuracy or greater continue to complete an additional 20 trials. These additional trials feature stimuli of (1) arrow icons rather than fish icons and (2) utilize a "Home Base" to obtain a measure of reaction time (Figure 3). Participants were instructed to rest their finger on Home Base before the trial began and return it after indicating their selection. The Flanker assessment generated raw scores and age-adjusted scores for each participant (Slotkin, Kallen, Griffith, Magasi, Salsman, Nowinski, & Gershon, 2012). "Home Base" provides participants with a consistent distance from the iPad screen from which they can indicate their selection and assists in the computation of reaction time scores between participants. Reaction time scores were summed with age-adjusted scores to produce combination scores that could be compared between participants who completed all 40 trials. Thus, all 12 participants have raw and age-adjusted scores, however 6 out of 12 total participants (4 CI users, 2 NH peers) had reaction time scores. For this reason, as well as the non-longitudinal nature of this study, we utilized age-adjusted scores for comparison and did not include combination scores in the analyses.

Transcription and scoring

All MLI was transcribed verbatim using PRAAT software, a program for speech analysis that can provide an acoustic evaluation of speech samples (van Lieshout, 2003). Utterances were transcribed according to Systematic Analysis of Language Transcripts (SALT) software standards for language sample analysis (Miller, 2018). SALT transcription conventions were utilized to ensure consistency and reliability between independent coders. SALT provides spelling conventions for common utterances with semantic significance, such as “uhhuh” and “mhm” for affirmative words and “mhmh” and “uhuh” for negation words (Miller, 2018). Further, SALT provides standards for context effects on speech such as the use of angle brackets < > for overlapping speech and parentheses ( ) for repetitions within speech (Miller, 2018). Utterances with grammatical errors were transcribed with codes in brackets [ ] to indicate word-level errors, utterance-level errors, extraneous words, overgeneralization errors, non-standard word order, and fragmented speech.

Final transcripts were categorized and sorted using Microsoft Excel. MLI was measured qualitatively with each utterance coded into 1 of 7 categorizes: (1) physical directives that instruct the child on their physical behavior (“Sit down”); (2) attentional directives that instruct the child to control or redirect their visual attention (“Look at these blocks); (3) open-ended questions that provide the child with a question to which they can freely respond (“What do you want to build?”); (4) closed-ended questions that prompt the child to provide only a 1-word response (“What color is this block?”); (5) child interruptions in which the child breaks the continuity of their mother’s speech (Mother begins saying “It’s time to clean-“ when child says, “No!”); (6) maternal interruptions in which the mother breaks the continuity of their child’s speech (Child begins saying "I'm going to put this-" when mother says, "You can put that here"); (7) other which includes all other input not specified by any other category ("Good job!"). Utterances were quantitatively measured by calculating the total number of maternal utterances and total number of child utterances. Within each maternal utterance, the total number of word tokens was calculated and summed to produce a total number of maternal words in the transcript. This process was repeated with morphemes to produce a total number of maternal morphemes in the transcript. The mean length of utterance was calculated using the total number of words and morphemes, respectively, and dividing them by the total number of spoken utterances in the session. Finally, mother-child conversational turns were measured, or each occurrence of a mother's utterance followed by a child's utterance, or vice versa, with no more than a 5 second pause between them (Romeo et al., 2018). Conversational turns provide a final quantitative measurement of MLI that assesses the fluidity of dialogue between a mother and child.

To establish inter-rater reliability between transcripts, 3 independent transcribers coded 4 play sessions and transcripts were assessed line-by-line until achieving 100% reliability. One of these transcribers continued to transcribe all remaining play sessions as the "gold standard" for reliability. A second transcriber also continued to transcribe all remaining play sessions against the "gold standard" transcriber, consulting line-by-line until achieving 100% reliability. One-third of the remaining play sessions were transcribed by the third transcriber against the "gold standard" transcriber, also consulting line-by-line until achieving 100% reliability. This process was repeated with the same "gold standard" transcriber and 2 different coders to establish inter-rater reliability for coding MLI until 100% reliability was achieved for all quantitative and qualitative measures.

Planned Analyses

Descriptive statistics were summarized for participant demographic variables, including child's race, ethnicity, gender, and mother's highest completed level of education, total number of children in the family, and family income. These analyses were used to evaluate demographic differences across hearing status (NH and CI). Participants were an average 4.61 years old (*SD* = .92) at testing. Nonverbal intelligence was evaluated, and participants averaged a score of 110 (*SD* = 17.57) on the PTONI assessment. Hearing history variables for CI participants are provided in Table 1. Etiology of hearing loss included genetic (*n* = 1, 16.7%), Mondini Malformation (*n* = 1, 16.7%), Usher's Syndrome (*n* = 1, 16.7%), and unknown (*n* = 3, 50%). One CI participant reported using total communication while all other participants reported using oral communication strategies (*n* = 5, 83.3%). This CI participant also completed the free-play task with her father and thus her father's linguistic input was transcribed and categorized.

Descriptive statistics were summarized for the quantitative measures of MLI, including (1) total number of child utterances, (2) total number of maternal utterances, (3) total number of word tokens, (4) MLU in word tokens, (5) total number of morphemes, (6) MLU in morphemes, and (7) total number of conversational turns. Descriptive statistics were summarized for the qualitative measures of MLI categories, including (1) physical directives, (2) attentional directives, (3) closed-ended questions, (4) open-ended questions, (5) maternal interruptions, (6) child interruptions, and (7) all other utterances.

MANOVAs assessed group differences in MLI metrics and MLI categories based on hearing status and gender. Independent sample *t*-tests were conducted to compare the performance of NH and CI groups on the PTONI assessment for nonverbal intelligence and the Flanker Task for inhibition-concentration skills. MANOVAs assessed group differences in language skills between NH and CI groups which included scaled scores from subtests of the

CELF-P, including *Sentence Structure*, *Word Structure*, and *Expressive Vocabulary,* and age-corrected Standard scores. Pearson product correlations were conducted to examine associations between MLI and executive functioning skills.

Chapter 3

Results

Descriptive statistics revealed no significant differences in age at testing, maternal educational level, family income, or number of children in the family as a function of hearing status and gender (see Table 1). No differences were observed between CI users and NH controls in nonverbal intelligence as measured by the PTONI (p = .579).

A MANOVA compared MLI variables on quantitative measures as a function of hearing status and gender and only revealed a marginally significant main effect of hearing status (F (7, 2) = 20.33, p = .048; see Table 2). A MANOVA compared MLI variables on qualitative measures as a function of hearing status and gender and only revealed a significant main effect of hearing status (F (5, 4) = 14.42, p = .011; see Table 3). Planned pairwise comparisons revealed that CI users received significantly more total maternal utterances (M = 183.50, SD = 29.78) than their NH peers (M = 138.00, SD = 19.07; p = .018; see Table 4). Planned pairwise comparisons also revealed that CI users received significantly more physical directives (M = 12.33, SD = 4.89) and attentional directives (M = 23.67, SD = 11.64) than NH peers (M = 3.67, SD = 2.94; p = .008; M = 7.83, SD = 3.54; p = .017, respectively; see Table 5). These findings indicate that CI users received more MLI and that their mothers utilized more directives than mothers of NH peers to control their behavior and attention.

One CI user was not administered the CELF-P assessments due to child behavior, and so the total number of participants included in subsequent analyses involving these assessments is N = 11. A MANOVA compared the CELF-P subscales *Sentence Structure*, *Word Structure*, and *Expressive Vocabulary* scores and the age-corrected Standard scores as a function of hearing status and gender and revealed no significant main effects, suggesting no difference in language skills between CI users and NH peers (see Table 5). A t-test comparing age-corrected Flanker scores as a function of a hearing status revealed no significant differences (t (10) = -1.17, p = .270), indicating comparable inhibition-concentration skills (see Table 6).

Correlations Collapsed Across Hearing Status

Pearson product correlations were run to examine possible associations between MLI, demographic factors, and neurocognitive skills collapsing across hearing status (see Table 7). Significant correlations were observed between maternal educational level and mothers' utterance complexity. Specifically, longer MLU in word tokens (r = .559, p = .029) and morphemes (r = .554, p = .031) were significantly correlated with higher maternal educational level, suggesting mothers with higher completed levels of education used longer utterances with greater complexity. Total number of child utterances was positively correlated with PTONI scores (r = .513, p =.044), and the total number of conversational turns between child and mother were also positively correlated with PTONI scores (r = .556, p = .030), suggesting that participants with higher nonverbal intelligence scores produced more utterances and engaged in more conversational turns with their mothers. CELF-P *Sentence Structure* scaled scores were negatively correlated with the total number of maternal utterances (r = -.524, p = .049), attentional directives (r = -.631, p = .019), and total directives (r = -.571, p = .033), suggesting participants who received a higher number of maternal utterances and a higher number of directives exhibited a poorer ability to evaluate spoken sentences of increasing length and complexity. CELF-P *Sentence Structure* scaled scores were also positively correlated with total number of conversational turns (r = .564, p = .035), suggesting that participants with a higher ability to interpret spoken sentences of increasing length and complexity and engaged in better conversational skills with their mothers. CELF-P *Word Structure* scaled scores were positively correlated with MLU in word tokens (r = .684, p = .010), MLU in morphemes (r = .697, p = .009), and total number of conversational turns (r = .563, p = .036), suggesting that participants who received more complex language from their mothers and engaged in more conversational turns exhibited greater morphological skills. CELF-P *Word Structure* scaled scores were also negatively correlated with mothers' total number of closed-ended (r = -.591, p = .028) and open-ended (r = -.645, p = .016) questions, suggesting that participants who received more questions from their mothers exhibited poorer morphological skills. Similarly, CELF-P *Standard* scores were positively correlated with MLU in word tokens (r = .528, p = .047), MLU in morphemes (r = .542, p = .043), and total number of conversational turns (r = .554, p = .039), suggesting participants who received more complex language from their mothers and engaged in more conversational turns exhibited greater global language skills. Additionally, CELF-P *Standard* scores were negatively correlated with total number of open-ended questions (r = -.578, p = .031), suggesting participants who received more maternal questions exhibited poorer global language skills. Finally, Flanker scores were negatively correlated with both total number of attentional directives (r = -.586, p = .023) and total directives (r = -.568, p = .027), suggesting participants that received more directive MLI exhibited poorer inhibition-concentration skills.

Correlations Within Hearing Status

Pearson product correlations were run to examine possible associations between MLI, demographic factors, and neurocognitive skills within each hearing status group. Within CI users (see Table 8), CELF-P *Sentence Structure* scaled scores were positively correlated with MLU in word tokens (r = .896, p = .020), MLU in morphemes (r = .927, p = .012), and physical directives (r = .891, p = .021), suggesting that CI users who received more complex maternal language and more instructions from their mothers to regulate their physical behavior exhibited a greater ability to interpret spoken sentences of increasing length and complexity. Similarly, CELF-P *Word Structure* scaled scores were positively correlated with MLU in word tokens (r = .912, p = .015), MLU in morphemes (r = .936, p = .010), and physical directives (r = .933, p =

.010), suggesting that CI users who received more complex maternal language and more maternal instructions to regulate their physical behavior exhibited poorer morphological skills. CELF-P *Word Structure* scaled scores were negatively correlated with open-ended questions (r = -.885, p = .023), suggesting that CI users who received more maternal questions exhibited poorer morphological skills. CELF-P age-corrected *Standard* scores were also positively correlated with MLU in word tokens (r = .917, p = .014), MLU in morphemes (r = .938, p = .009), and physical directives (r = .889, p = .022), suggesting that CI users who received more complex maternal language and more maternal instructions to regulate their physical behavior exhibited poorer global language skills. CELF-P age-corrected *Standard* scores were also negatively correlated with open-ended questions (r = -.829, p = .041), indicating CI users who received more open-ended questions demonstrated poorer morphological skills. CELF-P *Expressive Vocabulary* scaled scores were positively correlated with total number of child interruptions (r = .839, p = .038), suggesting that CI users who frequently interrupted their mothers' speech exhibited greater abilities to provide labels for people, objects, and actions. Contrastingly, CELF-P *Expressive Vocabulary* scaled scores were negatively correlated with total number of maternal interruptions (r = -.849, p = .035), suggesting that CI users who were frequently interrupted by their mothers' speech exhibited poorer abilities to provide labels for people, objects, and actions.

Within NH participants (see Table 9), age at testing visit was positively correlated with PTONI (r = .890, p = .009) and Flanker scores (r = .900, p = .007), suggesting that nonverbal intelligence and inhibition-concentration skills increase with age for preschool aged NH children. Maternal educational level was positively correlated with total number of maternal utterances (r = .745, p = .045) and total number of conversational turns (r = .749, p = .043), suggesting mothers who completed higher levels of education produce more utterances and engaged in more conversational turns with their children. Maternal educational level was negatively correlated with total number of open-ended questions (*r* = -.735, *r* = .048), suggesting mothers of NH children who completed higher levels of education asked fewer open-ended questions. PTONI was correlated with CELF-P *Word Structure* scaled scores (*r* = .744, *p* = .045) and Flanker scores (*r* = .745, *p* = .045), suggesting NH participants with greater nonverbal intelligence exhibited greater morphological skills and greater inhibition-concentration skills. PTONI was also negatively correlated with total number of attentional directives (*r* = -.894, *p* = .043) and total number of child interruptions (*r* = -.844, *p* = .017), suggesting that NH participants with greater nonverbal intelligence received fewer instructions from their mothers to redirect their attention and interrupted their mothers' speech less frequently. CELF-P *Word Structure* scaled scores were negatively correlated with total number of attentional directives (*r* = -.796, *p* = .029) and total number of directives (*r* = -.901, *p* = .007), suggesting that NH participants who received fewer maternal instructions to redirect their behavior and attention exhibited greater morphological skills. CELF-P *Sentence Structure* scaled scores were also negatively correlated with total number of directives (*r* = -.841, *p* = .018), suggesting that NH participants who received fewer maternal instructions to redirect their behavior and attention exhibited greater morphological skills. Similarly, CELF-P age-corrected *Standard* scores were negatively correlated with total number of directives (*r* = -.850, *p* = .016), suggesting that NH participants who received fewer maternal instructions to redirect their behavior and attention exhibited greater global language skills. Finally, Flanker scores were negatively correlated with total number of child interruptions (*r* = -.782, *p* = .033), suggesting that NH children with poorer inhibition-concentration skills interrupted their mothers' speech more frequently and demonstrated poorer inhibition-concentration skills.

Chapter 4

Discussion and Conclusions

The purpose of this study was to understand the relationships between MLI and executive functioning skills and addressed 2 main hypotheses: (1) CI users would perform worse on the Flanker task, indicating poorer inhibition-concentration skills, as compared to their NH peers, and (2) there would be an observable correlation between MLI and executive functioning skills for both CI users and their NH peers. While the literature demonstrates support for the first hypothesis, limited research exists with preschool CI users and limited research has been conducted using the Flanker task to measure executive functioning skills. Additionally, limited research has been conducted to support or reject the second hypothesis.

Neurocognitive Differences Between Groups

PTONI scores revealed no significant differences as a function of hearing status, indicating negligible differences in nonverbal intelligence between both groups. No significant group differences were observed between CI users and NH peers in subtests of the CELF-P, including *Word Structure*, *Sentence Structure*, and *Expressive Vocabulary*, as well as the Standard CELF-P scores, indicating no significant differences in language skills between CI users and NH peers. However, differences in CELF-P Standard scores were trending between groups (F (1,7) = 3.98, p = .09), suggesting potentially significant differences in global language between groups. While this finding is trending, further study with an increased sample size may reveal significance.

In reference to our first hypothesis, no significant differences were observed in Flanker scores between NH and CI groups, indicating no significant differences in inhibition-concentration skills. This finding differs from previous studies observing significant differences in executive functioning skills in a pediatric sample with varying degrees of hearing loss

(Figueras, Edwards, & Langdon, 2008). Our results may be explained by the small sample size included in this study. The inclusion of 5 CI users and 6 NH peers created a small dataset that limited our ability to detect differences between groups. Further, the Flanker task specifically measures inhibition-concentration skills and did not measure differences in other executive functioning skills, such as working memory and attentional shifting, that may have been present in this sample (Diamond, 2005). However, our finding of negligible differences in inhibition-concentration skills between groups is not surprising given our finding of negligible differences in global language skills between groups because of the associations between these areas of neurocognitive development in preschool aged children (Hunter, Kronenberger, Castellanos, & Pisoni, 2017). Analysis of neurocognitive assessments from this dataset suggest comparable performance in nonverbal intelligence, global language skills, and inhibition-concentration skills between CI users and NH peers.

MLI Differences Between Groups

Both metric and categorical variables of MLI were statistically different between groups. Our findings demonstrate that there is no difference in intelligence between CI users and their NH peers, but there were differences in MLIs. Majorano & Lavelli (2013) found that mothers fine-tune their language in response to their child's linguistic abilities. Our results thus support that mothers' use of language does not differ between groups as a function of children's perceived intelligence, but rather as a function of children's perceived language skills. Our findings also indicate that CI users received more maternal utterances their NH peers, contrasting with previous research indicating that differences in the total amount of MLI is negligible between groups (Fagan et al., 2014). CI users received significantly more physical and attentional directives than NH peers and this is consistent with previous literature (Fagan et al., 2014). In mixed-hearing dyads, as compared to matched-hearing dyads, mothers provided a greater total number of utterances to children and this may be attributed to an increased frequency of directive speech that commanded their child's behavior and attention during the free-play task. Mothers' use of physical and attentional directives instructs children with shorter utterances rather than engages them in dialogue (Bergeson et al., 2006). The increased frequency of these directives in mixed-hearing dyads indicates that CI users receive less complex linguistic input than their NH peers.

However, the strongest assessment of MLI complexity is through measurement of MLU in words and morphemes. Despite our observations of directives, neither MLU in words nor MLU in morphemes were found to be significantly different between mixed-hearing and matched-hearing dyads. This finding contrasts with previous literature indicating mothers in mixed-hearing dyads provide less complex language and produce shorter MLUs (DesJardin & Eisenberg, 2007). Our current analyses of MLUs indicate no significant differences in complexity of maternal language provided between groups.

Associations Collapsed Across Hearing Status

Our second hypothesis was tested through correlations collapsed across hearing status. Maternal educational level was positively associated with MLU in word tokens and MLU in morphemes, supporting previous literature indicating associations between maternal educational level and maternal language complexity (Boones et al., 2013; Geers et al., 2009; Magnuson et al., 2009). Positive associations were also observed between PTONI scores and the total number of child utterances as well as the total number of conversational turns. These findings may suggest that increased speech-language skills are associated with increased intelligence. However, the nonverbal intelligence variable may be confounding. Nonverbal intelligence was also associated with children's age and the literature explains that speech-language skills are associated with NH children's age and CI users' hearing age (Bergeson et al., 2006). The CELF-

P *Sentence Structure* scaled scores were also positively associated with the total number of conversational turns. However, CELF-P *Sentence Structure* scaled scores were negatively associated with the total number of maternal utterances and the total number of directives (Figure 4). These findings suggest that some, but not all, strategies of MLI are linked with greater comprehension of spoken sentences. As DesJardin, Ambrose, and Eisenberg (2008) summarize, MLI that facilitates children's expressive language is associated with children's language development. However, strategies such as physical and attentional directives, which may have increased total maternal utterances, are not associated with better language skills in children and thus may explain the negative association between maternal utterance total and children's comprehension of spoken sentences. In contrast, conversational turns have been found to promote verbal language skills (Romeo et al., 2018) and thus may be positively associated with children's comprehension of spoken sentences.

Positive associations were observed between CELF-P *Word Structure* scaled scores and MLU in word tokens and MLU in morphemes as well as the total number of conversational turns (Figure 5). This supports our expectation that increased complexity in maternal language is associated with greater language skills in children. Interestingly, CELF-P *Word Structure* scaled scores were negatively correlated with the total number of both open-ended and closed-ended questions. Open-ended questions have been understood in the literature as more complex than closed-ended questions for initiating dialogue between mothers and children (DesJardin & Eisenberg, 2007; DesJardin et al., 2008), however these MLI categories were not associated with greater comprehension of morphological rules involved in word-level comprehension among children. These findings suggest that even complex MLI does not promote all aspects of children's language development, including morphological skills.

The CELF-P Standard score provides a holistic understanding of global language skills in relation to MLI collapsed across hearing status groups. CELF-P Standard scores were positively associated with MLU in word tokens, MLU in morphemes, and the total number of conversational turns. This suggests that increased complexity in maternal language is associated with language skill development and the duality of this interaction is exhibited through increased conversational turns among dyads. Despite these findings, CELF-P Standard scores were negatively associated with open-ended questions, rejecting the notion that increasingly complex MLI would be associated with increased language skills. This may be explained by mothers' trial-and-error of scaffolding to their child's perceived language skills. While open-ended questions have been associated with eliciting language, this can be ineffective for children who lack conversational skills and vocabularies that are advanced enough to produce elongated responses. Finally, a negative association was observed between Flanker scores and attentional directives, and this finding provides support for our second hypothesis (Figure 6). This suggests that mothers use language to redirect their children's visual attention based on a perceived lack of inhibitory skills. Further, children who received more attentional directives demonstrated poorer inhibitory skills on the Flanker task, substantiating this association.

Associations Within Hearing Status Groups

Correlational data provides some support for our second hypothesis. Among NH participants, age at testing was positively associated with PTONI and Flanker scores, indicating that nonverbal intelligence and executive functioning skills increase with age. These findings align with previous research indicating that the preschool age is a period of rapid neurocognitive development (Zelazo & Carson, 2014). Maternal educational level was positively associated with mothers' MLU in both word tokens and morphemes as well as the total number of conversational turns, supporting previous findings that mothers with higher education provide more complex speech to children (Hoff, 2003; Geers et al., 2009). Surprisingly, maternal educational level was negatively associated with open-ended questions, which have been previously discussed as more complex MLI strategies than closed-ended questions (DesJardin, Ambrose, & Eisenberg, 2008; DesJardin & Eisenberg, 2007). Positive associations between PTONI scores and CELF-P *Word Structure* scores suggest a link between higher intelligence and an increased understanding of morphological rules among NH children. In contrast, negative associations between PTONI scores and total number of attentional directives and child interruptions suggest potential associations with executive functioning skills. Children with lower nonverbal intelligence exhibited less inhibitory behavior, demonstrated by frequently breaking the continuity of their mothers' speech, and received more directives from their mothers to control their visual attention. Further, negative associations that were observed between the total number of child interruptions and Flanker scores also suggest an association between limited inhibition skills and poorer executive functioning skills (Figure 7). These findings observed in NH children support our second hypothesis that an association exists between MLI and children's executive functioning skills.

Associations with the CELF-P assessments in NH participants also provide insight on the influence of language skills in our second hypothesis. Negative associations between CELF-P *Word Structure* scaled scores and the total number of directives may suggest a link between MLI and executive functioning. As previously discussed, the development of children's language skills and executive functioning skills are related (Hunter, Kronenberger, Castellanos, & Pisoni, 2017). In our study, NH children with poorer morphological skills received a higher frequency of maternal instruction to redirect their behavior and attention, suggesting a lack of inhibition, and this supports an association between language skills and executive functioning skills. Similarly, negative associations between the CELF-P *Sentence Structure* scaled scores and the CELF-P

Standard scores with the total number of directives suggest a link between language skills and executive functioning skills. NH children with poorer comprehension of spoken sentences and poorer global language skills received a higher frequency of maternal instruction to redirect their behavior and attention. Among NH children, a lack of perceived executive functioning skills, suggested by mothers' use of physical and attentional directives, was associated with poorer language skills.

Our second hypothesis can also be evaluated through correlational data among CI participants. MLU in word tokens and morphemes were positively associated with CELF-P subtests, including *Sentence Structure* and *Word Structure*, as well as CELF-P Standard scores. This indicates an association between more complex MLI and better global language skills in CI users and this is consistent with the literature (DesJardin, Ambrose, & Eisenberg, 2008; DesJardin & Eisenberg, 2007). Similarly, the negative association between mothers' use of open-ended questions and CELF-P *Word Structure* scaled scores indicates the opposite effect: less complex MLI is associated with poorer morphological skills in CI users. Positive associations were observed between CELF-P *Expressive Vocabulary* scores and the total number of child interruptions, providing an interesting association between participants' ability to name target images and their inhibitory skills. CI users who more frequently interrupted their mothers and broke the continuity of dialogue exhibited greater abilities to provide labels for people, objects, and actions. Though this does not support the positive association between children's language and executive functioning skills that we hypothesized, it may be attributed to our CI users' participation in oral educational programs that promote the development of expressive language skills without providing focused therapy on executive functioning skills. CELF-P *Expressive Vocabulary* scaled scores were negatively associated with maternal interruptions and this may be understood through a mechanism involving MLI and executive functioning skills. Mothers often interrupt or overlap their children's speech to redirect their children's behavior or enforce a correction (Bergeson et al., 2006). The use of maternal interruptions in this manner may suggest poorer executive functioning abilities for CI users and, subsequently, poorer language development for CI users as the two skills are closely associated (Hunter, Kronenberger, Castellanos, & Pisoni, 2017). Surprisingly, CELF-P *Sentence Structure* and *Word Structure* scaled scores and CELF-P Standard scores were positively associated with the total number of physical directives, suggesting relationships between morphological, sentence-level, and global language skills and maternal language that is used to control children's physical behavior. As physical directives are interpreted in the literature as less complex language (DesJardin & Eisenberg, 2007), this indicates CI users who received less complex MLI demonstrated greater language skills. While this contrasts with our expectation of increased MLI complexity being associated with better language skills, this finding may be attributed to mothers' increased use of imperative language in mixed-hearing dyads compared to matched-hearing dyads (Bergeson et al., 2014; Fagan et al., 2014).

The associations between MLI and executive functioning skills were evaluated in this study through qualitative and quantitative analysis of MLI in mixed-hearing and matched-hearing dyads and assessment of inhibition-concentration skills for pediatric CI users and their peers. We hypothesized that (1) CI users would display poorer inhibition-concentration skills and subsequently perform worse on the Flanker task than NH peers and (2) there would be observable relationships between MLI and executive functioning skills. Our results revealed no significant differences in inhibition-concentration skills between CI users and NH peers, rejecting our first hypothesis. However, several associations were observed between MLI and executive functioning skills across hearing status that provided support for our second hypothesis. Further, we observed associations between MLI and children's language skills and between children's language skills and executive functioning skills, suggesting a relationship between these domains of neurocognitive development (Hunter, Kronenberger, Castellanos, & Pisoni, 2017).

Limitations

Interpretations of these findings must acknowledge the limitations of this study. First, this study used a small sample size of 12 mother-child dyads, 6 mixed-hearing and 6 matched-hearing status. The pediatric CI population is intrinsically small and the exclusionary criteria for this study further decreased the pool of potential participants for recruitment. Findings between CI and NH groups that did not match our hypotheses or reviewed literature may be due to our inability to detect differences within this small sample size and significance values could fluctuate with minimal additions to the sample. Second, the dataset for the CI population in this study further decreased in size due to an exclusion. One CI participant was behaviorally unable to complete CELF-P assessments and so subsequent data comparing CELF-P results across hearing status and correlations with other assessments was completed with one fewer participant's data.

Further Study

This study has significant implications for the development of clinical interventions to improve children's executive functioning skill development. Research on maternal language and maternal contributions has focused on family empowerment models to provide families with skills to promote language skills in their home environments (DesJardin & Eisenberg, 2007; DesJardin, Ambrose, & Eisenberg, 2008). As summarized by DesJardin and Eisenberg (2007), family-centered intervention programs are designed to increase mothers' efficacy and knowledge on effective maternal linguistic techniques that aid their children's communication. Improved understanding of the associations between MLI and executive functioning skills could expand on these programs to improve children's executive functioning skill development as well. Further study with an increased sample size is critical to understanding the associations between MLI and executive functioning skills for pediatric CI users to optimize strategies that can enhance neurocognitive development.

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Appendix A: Figures

Figure 1. Mother-child free-play set up with age-appropriate toys. Mothers were instructed to (1) play with their child as they would naturally play at home and (2) instruct their child to only play with the toys provided on the table.

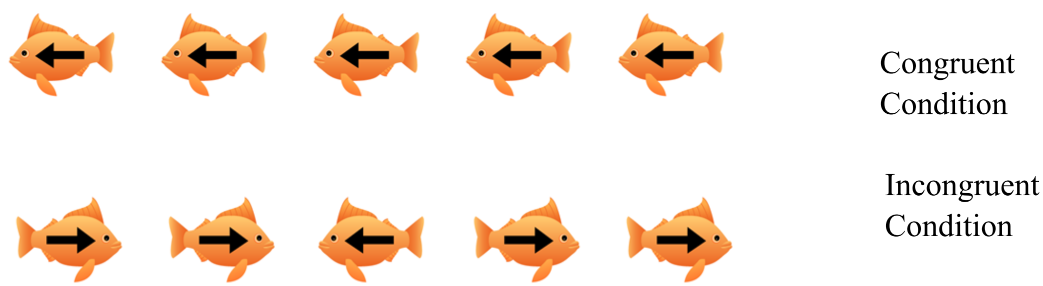

Figure 2. Congruent and incongruent trials of Flanker Inhibitory Control and Attentional Test of NIH Toolbox. The task measured participants' inhibition-concentration skills through their ability to differentiate the middle fish from the flanking fish. The congruent condition is represented by the middle fish facing the same direction as the flanking fish. The incongruent condition is represented by the middle fish facing the opposite direction as the flanking fish.

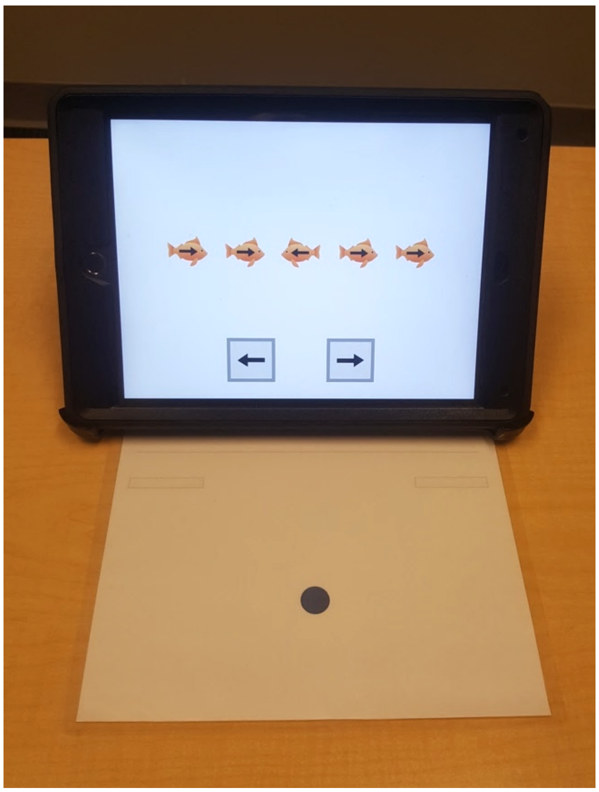

Figure 3. Set up for Flanker Inhibitory Control and Attentional Test of NIH Toolbox. Home Base (blue dot) is used to measure reaction time. Participants were asked to select the arrow corresponding to the direction that they perceived the middle fish was facing. Participants who continued to the final 20 trials were asked to place their finger on Home Base in between trials.

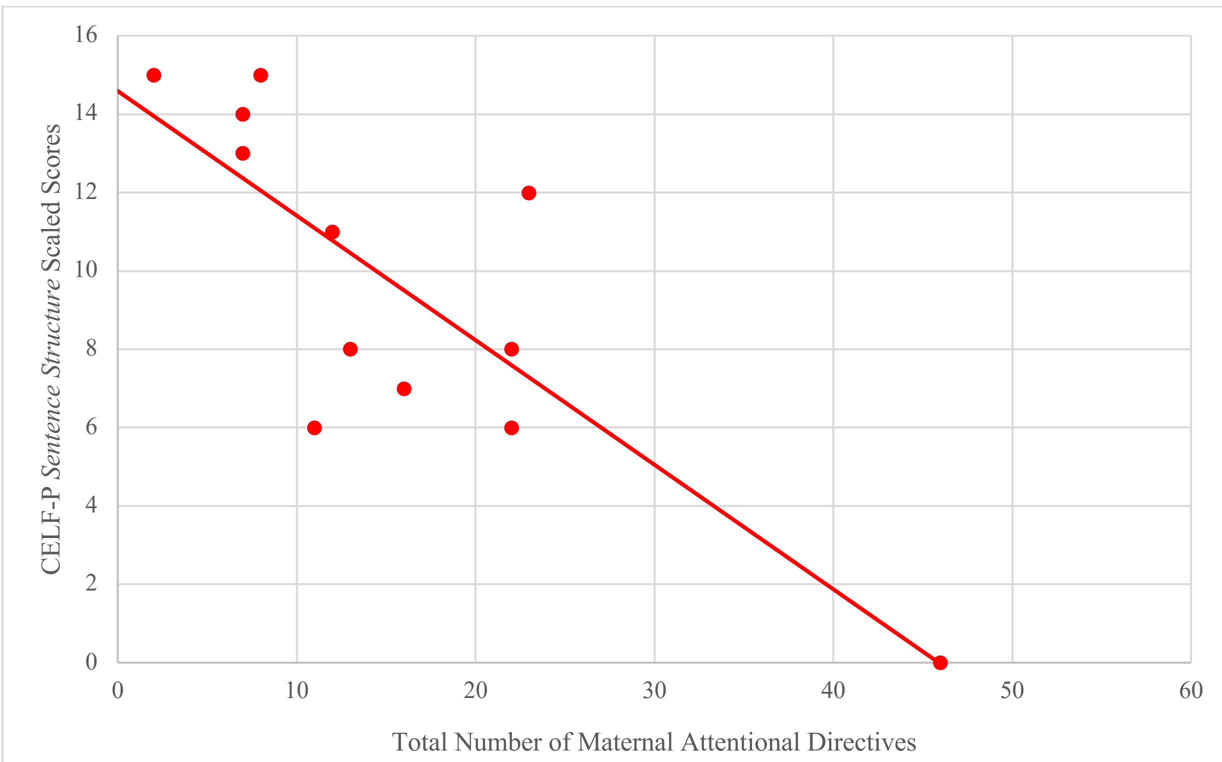

Figure 4. Correlation between the total number of attentional directives and CELF-P *Sentence Structure* scaled scores collapsed across hearing status. A negative correlation was observed between attentional directives and CELF-P *Sentence Structure* scaled scores.

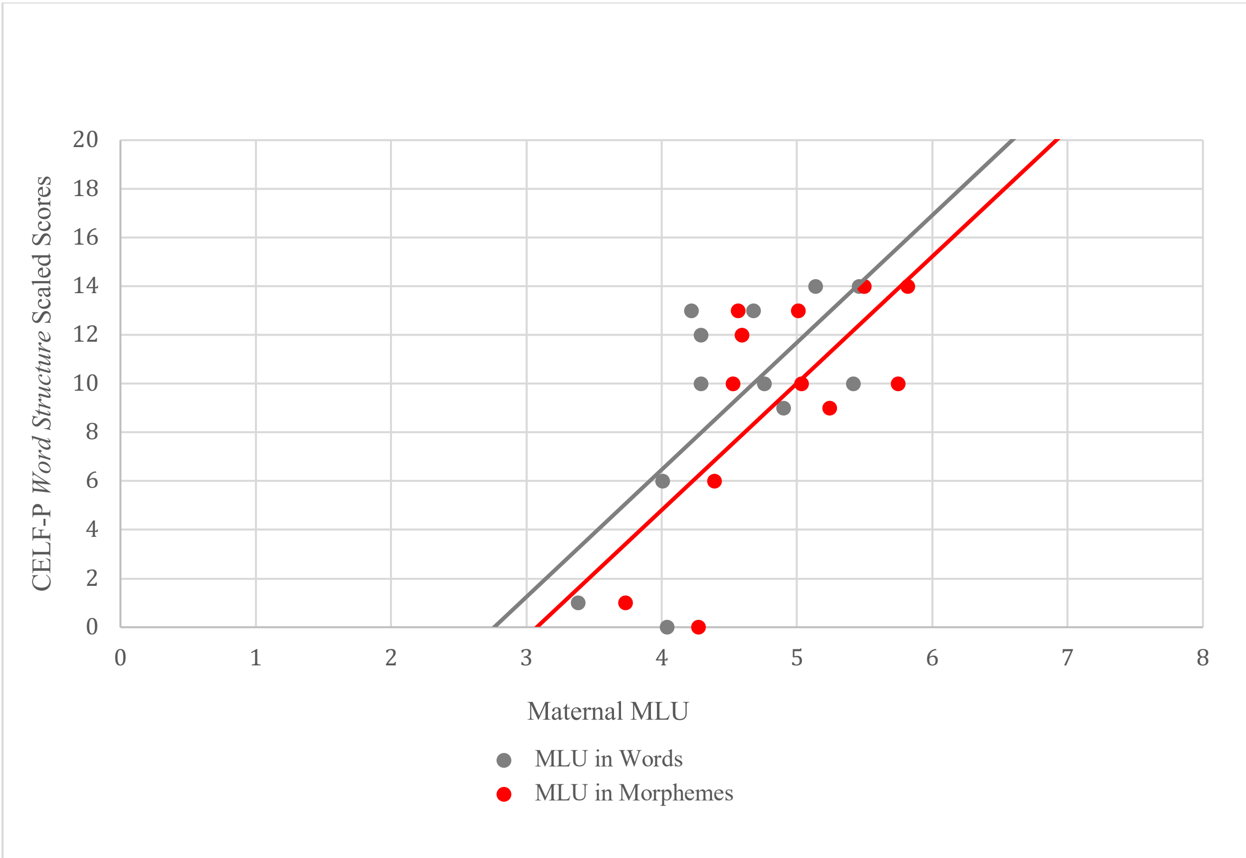

Figure 4. Correlations between CELF-P *Word Structure* scaled scores and MLU in Word Tokens (grey) and MLU in Morphemes (red) collapsed across hearing status. Positive correlations were observed for both MLU in Word Tokens and MLU in Morphemes with CELF-P *Word Structure* scaled scores.

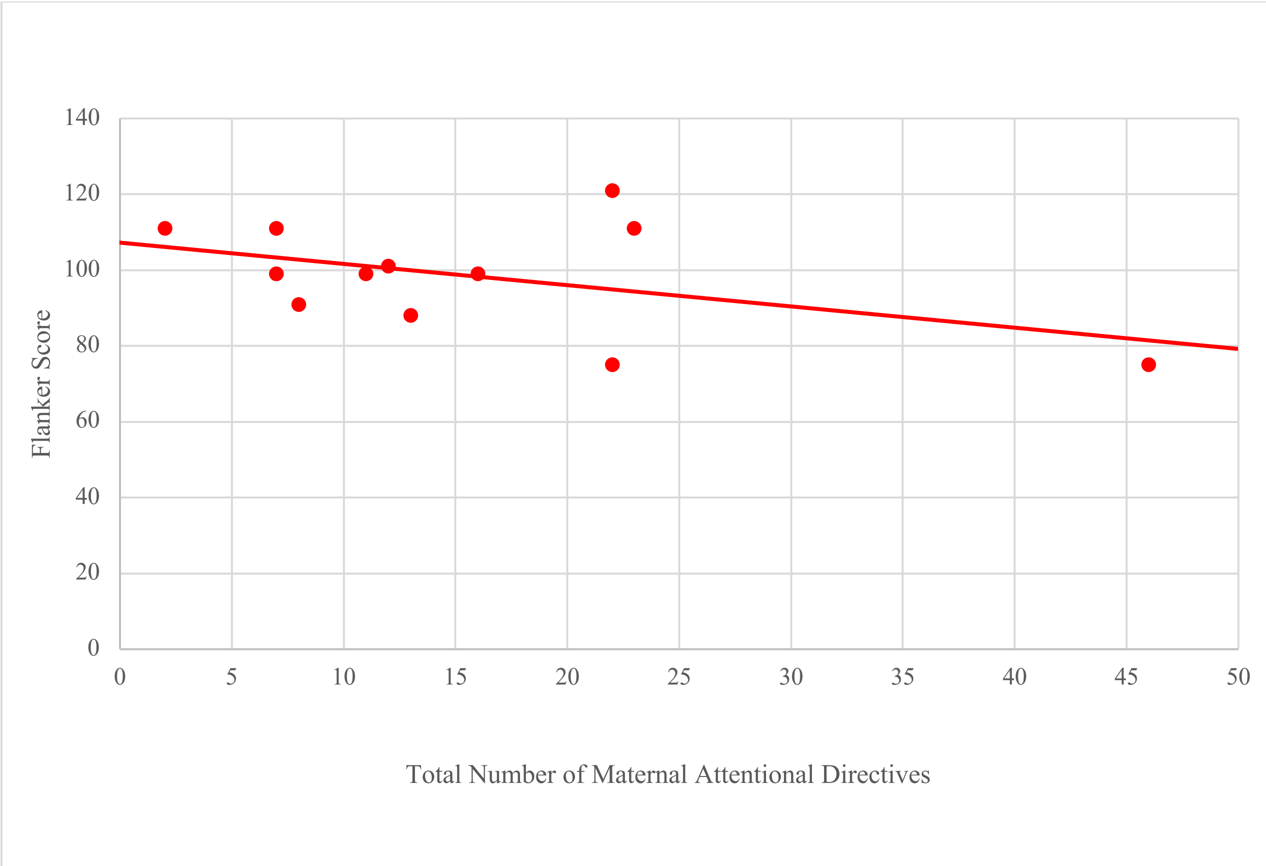

Figure 6. Correlation between the total number of attentional directives and Flanker scores collapsed across hearing status. A negative correlation was observed between the total number of attentional directives and Flanker scores.

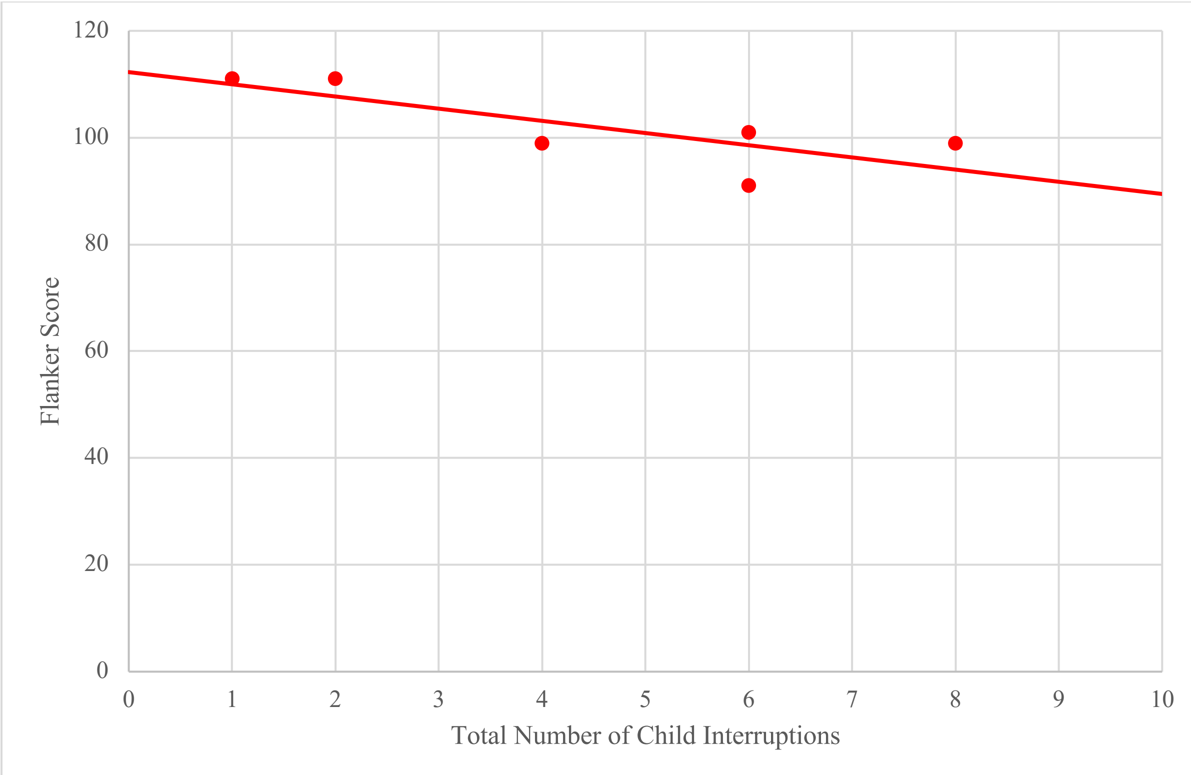

Figure 7. Correlation between the total number child interruptions and Flanker scores among NH participants. A negative correlation was observed between the total number of child interruptions and Flanker scores.

Appendix B: Tables

Table 1. *Participant demographics and hearing history.*

	Participants (N = 12)	
	M (SD)	Range
Age at testing (years)	4.61 (.92)	3.76 - 6.17
Nonverbal IQ	110.00 (17.57)	86.00 - 139.00
Income level[a]	8.50 (2.07)	5.00 - 10.00
Maternal education[b]	2.17 (1.03)	0.00 - 3.00
Number of children in family	2.42 (1.56)	1.00 - 7.00

	Hearing Status	
	CI (N = 6)	NH (N = 6)
	Count (% of CI sample)	Count (% of NH sample)
Etiology of hearing loss		NA
Genetic	1 (16.7%)	
Mondini Malformation	1 (16.7%)	
Ushers	1 (16.7%)	
Unknown	3 (50%)	
Communication Mode Rating Scale		NA
Sign/Total Communication	1 (16.7%)	
Oral/Cued Speech	5 (83.3%)	
Gender		
Male	2 (33.3%)	3 (50%)
Female	4 (66.7%)	3 (50%)
Race		
White	6 (100%)	4 (66.7%)
Black	0 (0%)	1 (16.7%)
Mixed Race	0 (0%)	1 (16.7%)
Ethnicity		
Hispanic	0 (0%)	0 (0%)
Non-Hispanic	6 (100%)	6 (100%)

Note. NA = not applicable. NH = normal hearing. CI = cochlear implant.

[a]Income level is coded on a scale from under $5,000 (coded 1) to $95,000 and over (coded 10) with a code of 8 = $65,000–$79,999 and a code of 9 = $80,000-$94,999.

[b]Maternal education is coded on a scale from high school degree (coded 0) to graduate degree (coded 3) with a code of 1 = some college and 2 = college degree.

Table 2. *MLI MANOVAs as a function of hearing status, gender, and hearing status x gender.*

N = 12

	F	*df*	*p*
Hearing Status			
MLI Metrics	20.33	7.00	.05*
MLI Categories	14.42	5.00	.01**
Gender			
MLI Metrics	2.20	7.00	.35
MLI Categories	1.04	5.00	.50
Hearing Status x Gender			
MLI Metrics	.41	7.00	.84
MLI Categories	.52	5.00	.75

Table 3. *Group differences in MLI metrics.*

	Hearing Status				
	CI (N = 6)	NH (N = 6)			
	M (SD)	M (SD)	F	df	p
Child's Total No. of Utterances	85.33 (29.68)	106.50 (24.22)	1.64	1.00	.24
Mother's Total No. of Utterances	183.50 (29.78)	138.00 (19.07)	8.83	1.00	.02*
Total No. of Word Tokens	798.00 (205.43)	665.67 (151.44)	1.47	1.00	.26
MLU in Word Tokens[a]	4.32 (.71)	4.77 (.47)	1.51	1.00	.25
Total No. of Morphemes	853.17 (209.46)	711.83 (158.51)	1.57	1.00	.25
MLU in Morphemes[b]	4.63 (.77)	5.11 (.48)	1.62	1.00	.24
Total No. of Conversational Turns	45.00 (13.46)	55.33 (7.63)	2.31	1.00	.17

Note. [a]MLU in Words = the total number of word tokens provided by mothers / the total number of maternal utterances.
[b]MLU in Morphemes = the total number of morphemes provided by mothers / the total number of maternal utterances.

Table 4. *Group differences in MLI categorical variables.*

	Hearing Status				
	CI (*N* = 6)	NH (*N* = 6)			
	M (*SD*)	*M* (*SD*)	*F*	*df*	*p*
Total No. of Physical Directives	12.33 (4.89)	3.67 (2.94)	12.30	1.00	.01**
Total No. of Attentional Directives	23.67 (11.64)	7.83 (3.54)	9.01	1.00	.02*
Total No. of Closed-Ended Questions	35.67 (15.15)	19.83 (3.31)	4.91	1.00	.06
Total No. of Open-Ended Question	11.33 (5.57)	5.67 (3.78)	3.13	1.00	.12
Total No. of Other Utterances	88.67 (19.91)	90.00 (22.13)	.02	1.00	.90

Table 5. *CELF-P MANOVAs as a function of hearing status, gender, and hearing status x gender.*

N = 11

	F	*df*	*p*
Hearing Status	.61	4.00	.68
Gender	1.73	4.00	.30
Hearing Status x Gender	1.74	4.00	.30

Table 6. *Group differences in neurocognition measures.*

	Hearing Status				
	CI (N = 5)	NH (N = 6)			
	M (SD)	M (SD)	F	df	p
CELF-P *Sentence Structure*	8.20 (2.28)	12.33 (3.44)	3.61	1.00	.20
CELF-P *Word Structure*	6.80 (5.81)	11.83 (2.14)	2.42	1.00	.16
CELF-P *Expressive Vocabulary*	9.40 (3.29)	12.50 (2.07)	2.64	1.00	.15
CELF-P Standard	89.20 (18.99)	112.83 (13.56)	3.98	1.00	.09
	CI (N = 6)	NH (N = 6)			
	M (SD)	M (SD)	t	df	p
PTONI	107.00 (17.06)	113.00 (19,13)	-.57	10.00	.58
Flanker	88.17 (27.99)	102.00 (7.77)	-1.17	10.00	.27

Table 7. *Correlations collapsed across hearing status (N = 12).*

	Maternal Education	PTONI	*CELF-P SS[a]	*CELF-P WS[b]	*CELF-P EV[c]	*CELF-P Standard	Flanker
Total No. of Child Utterances							
r	-.30	.51	.51	.33	.15	.38	-.03
p	.17	.04*	.05*	.17	.33	.12	.46
Total No. of Maternal Utterances							
r	.17	-.43	-.52	-.30	-.14	-.37	-.45
p	.30	.08	.05*	.19	.37	.13	.07
MLU in Words							
r	.56	-.04	.26	.68	.43	.53	-.01
p	.03*	.45	.22	.01*	.10	.05*	.49
MLU in Morphemes							
r	.55	-.06	.27	.70	.44	.54	.03
p	.03*	.43	.21	.01**	.09	.04*	.46
Total No. of Attentional Directives							
r	-.47	-.39	-.63	-.42	-.32	-.51	-.59
p	.06	.10	.02*	.10	.17	.05*	.02*
Total No. of Directives							
r	-.47	-.34	-.57	-.31	-.36	-.45	-.57
p	.06	.14	.03*	.18	.14	.08	.03*
Total No. of Closed-Ended Questions							
r	.06	-.29	-.47	-.59	.05*	-.42	.08
p	.42	.18	.07	.03*	.45	.10	.40
Total No. of Open-Ended Questions							
r	.10	.04	-.47	-.65	-.41	-.58	.14
p	.38	.45	.07	.02*	.11	.03*	.34
Total No. of Conversational Turns							
r	.02	.56	.56	.56	.32	.55	-.11
p	.48	.03*	.04*	.04*	.17	.04*	.37

Note. * assessment indicates N = 11. [a]CELF-P SS = *Sentence Structure* scaled scores; [b]CELF-P WS = *Word Structure* scaled scores; [c]CELF-P EV = *Expressive Vocabulary* scaled scores.

Table 8. *Correlations among CI users.*

	CI (N = 5)			
	CELF-P SS[a]	CELF-P WS[b]	CELF-P EV[c]	CELF-P Standard
MLU in Words				
r	.90	.91	.53	.92
p	.02*	.02*	.18	.01**
MLU in Morphemes				
r	.93	.94	.52	.94
p	.01**	.01**	.18	.01**
Total No. of Physical Directives				
r	.89	.93	.41	.89
p	.02*	.01**	.25	.02*
Total No. of Open-Ended Questions				
r	-.77	-.89	-.40	-.83
p	.06	.02*	.25	.04*
Total No. of Child Interruptions				
r	.44	.24	.84	.53
p	.23	.35	.04*	.18
Total No. of Maternal Interruptions				
r	-.50	-.22	-.85	-.53
p	.19	.36	.04*	.18

Note. [a]CELF-P SS = *Sentence Structure* scaled scores; [b]CELF-P WS = *Word Structure* scaled scores; [c]CELF-P EV = *Expressive Vocabulary* scaled scores.

Table 9. *Correlations among NH participants.*

NH ($N = 6$)

	Maternal Education	PTONI	CELF-P SS[a]	CELF-P WS[b]	CELF-P EV[c]	CELF-P Standard	Flanker
Age at Testing Visit							
r	.04	.89	.23	.44	-.17	.18	.90
p	.47	.01**	.33	.19	.37	.37	.01**
PTONI							
r	.13	1	.53	.74	.15	.52	.75
p	.40		.14	.05*	.39	.14	.05*
Total No. of Maternal Utterances							
r	.75	-.41	-.48	-.20	-.16	-.35	-.41
p	.05*	.21	.17	.36	.38	.25	.21
Total No. of Conversational Turns							
r	.75	.24	.37	.73	.56	.56	-.31
p	.04*	.32	.24	.05*	.13	.12	.28
Total No. of Attentional Directives							
r	-.12	-.89	-.70	-.80	-.31	-.68	-.53
p	.41	.01**	.06	.03*	.27	.07	.14
Total No. of Directives							
r	-.39	-.68	-.84	-.90	-.58	-.85	-.37
p	.22	.07	.02*	.01**	.11	.02*	.24
Total No. of Open-Ended Questions							
r	-.74	.06	.32	.07	.41	.32	-.25
p	.05*	.46	.27	.45	.21	.27	.32
Total No. of Child Interruptions							
r	.28	-.84	-.72	-.58	-.24	-.60	-.78
p	.30	.02*	.05*	.11	.33	.11	.03*

Note. [a]CELF-P SS = *Sentence Structure* scaled scores; [b]CELF-P WS = *Word Structure* scaled scores; [c]CELF-P EV = *Expressive Vocabulary* scaled scores.